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Sustainable materials selection based on flood damage assessment for a building using LCA and LCC

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ABSTRACT

Flood risk is increasing rapidly around the world owing to the influence of climate change on precipitation levels. The refurbishment process is a complicated method of building construction after flooding. This study assesses all building costs in parallel with environmental emissions after repairs in a flood zone, in non-flood situations and when a flood hits the building, to determine the feasibility of repairs. Five types of building materials including common brick, concrete block, steel wall panels, wood, and precast concrete framing were assessed with a full life cycle assessment (LCA) and life cycle cost (LCC) assessment under non-flood, low-flood, and high-flood conditions. The result of greenhouse gas analysis showed that timber was the best choice for constructing the building, while, in case of flood occurrence, precast concrete framing shows better performance by releasing less CO_2 after the repair stage. The result of cost analysis indicated that despite timber being an ideal material for use in building construction, it is the costliest option in a high-flood situation due to its high repair costs. The benchmark results show that timber and steel frame were the worst materials to use in a flood zone, while brick was the most sustainable one. The findings of this paper prove that wood as a building material in flood zones is not ideal and that alternative materials such as brick have better functionality in terms of both global warming mitigation and LCC. The findings of this study provide insight into enhancing coordination among government bodies in the provision of post-disaster permanent housing adapted to climate change.

1. Introduction

Owing to the effects of global warming and climate change, the frequency, intensity, and magnitude of floods are increasing. However, these effects are not increasing in the whole world and some places have experienced less frequent or more intense events (Dong, 2017; De Paola, 2014). An increase in the intensity and frequency of extreme precipitation events is projected over most land areas as a consequence of global warming (Pachauri, 2012; Trenberth, 2011). Adaptation decisions are usually made under significant uncertainty owing to climate change and socio-economic trends (Abadie, 2017). Furthermore, due to rapid urbanisation and population growth, buildings are increasingly exposed to floods in urban areas. Climate change is currently viewed as one of the greatest threats to economic viability, security, environmental health, and territorial management on Earth (Adger, 2012). Cities have been identified as being among the human habitats most vulnerable to the effects of climate change (IPPC, 2007). East Malaysia is suffering from climate change consequences such as floods (Yau, 2013; Chan, 2012). Malaysia still does not have specific guidelines for housing construction after a disaster for disaster-prone areas (Roosli, 2011). The transition to climate-adaptive urban development is thus a major challenge facing delta cities across the globe, and one that urban planners, civil engineers, and policy-makers need to address (Carter, 2015). Monsoon floods affect only wall materials and most structures remain stable after a flood. Therefore, the assumption of this study is that structures are available for repair, and that houses near flood-prone areas must use different materials in their structures to lessen damage and promote sustainable maintenance and dismantling.

The project report Integrated Flood Risk Analysis (2016) identifies direct damage to buildings and their inventories as the most important type of damage in risk analysis. Among all natural

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hazards, floods are the costliest, especially in low-lying areas (Michel-Kerjan, 2015). The number of presidential disaster declarations associated with floods in Malaysia have increased substantially over the past 50 years (Saifulsyahira, 2016). Increases in coastal population and assets contribute to a rise in economic losses, and a significant amount of properties are lost each year to the increasing magnitude of flooding made worse by extreme climate change. Climate studies predict more intensive storm surge flooding in the future owing to storm activity changes and sea level rises (Lin, 2012; Buchanan, 2016) and thus more damage and losses. Ex post recovery might be significantly higher when recovering buildings. Many countries such as the United Kingdom, France, Norway and the Czech Republic have their own regulations/standards for flood disasters (Escarameia, 2012), but no specific guidelines have been available to assist homebuilders in rebuilding post-disaster homes in Malaysia (Roosli, 2016). However, at the international level, many guidelines have been prepared that have been found to be suitable for post-disaster housing. One of these instructions is related to building material use in flood zone areas.

Heavy rainfall has caused widespread flooding in the Malaysian states of Kelantan, Terengganu, Pahang, and Perak. The heavy raining and floods that occurred in 2014 were the worst in Malaysian history and damaged to infrastructure alone was estimated at USD 670 million (RM 2.851 billion) (MDMRH, 2016). The recent flood occurred in Pahang in 2007 and caused a huge economic loss of about USD 605 million. In 2010, the northern states of Perlis, Terengganu, and Kelantan were hit by continuous rain in what was estimated to be the worst flood in 30 years (Emanuel, 2005). Average losses are expected to increase because of the steady increase in population size in flood-prone regions in Malaysia (Webster, 2005). However, the government and private sectors still use conventional building materials after flood disasters without considering what material is the best option for an area. Adaptation is effective and increasingly urgent, regardless of climate uncertainties (Muis, 2015). The probability of a potentially damaging flood occurring is called the flood hazard, as damage depends on the vulnerability of the asset exposed to it. In general, a disaster can be referred to as a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes material, economic or environmental losses that exceed the community's or society's ability to cope using its own resources (IFRC, 2015).

This study does not propose shelters for post disaster relief but, instead, the repair and refurbishment of current structures. The advantage is lower costs and greater efficiency compared to new housing as well as greater accommodation than is provided by shelters. Transitional shelters (Escamilla, 2015) are not permanent and have a short lifetime (in some cases only a number of months). Assessment of this research estimates the economic and environmental carbon emission to reflect damage conditions, which is normally referred to as “loss or damage assessment” (Friedland, 2009).

There are some important studies regarding flood risk assessment. Nadal et al. (2010) developed a new stochastic methodology using Monte Carlo simulation to estimate the direct impact of five flood actions on buildings and to determine the expected damage. The results clearly indicated that the flood water hydrodynamics should not be neglected in the vulnerability assessment of buildings placed in flood prone zones. Scawthorn et al. (2006a, b) assessed the HAZUS-MH Flood Model for flood hazard in the United States. The researcher claims that the development of the HAZUS-MH Flood Model puts a powerful tool in the hands of communities, allowing proactive analysis and mitigation at the local level. De Risi et al. (2013) introduced a probabilistic and modular methodology to assess the flooding risk for structures in a portfolio of informal settlements through convolutions of flooding hazard and flooding fragility. The researchers have successfully implemented the proposed method in Dar es Salaam, Tanzania, and concluded that it can be applied in other urban contexts in Africa.

All new construction and improvements in flood zones should be constructed with materials resistant to flood damage. The question is whether these materials are sustainable, if they create lower CO_2eq emissions and have lower costs. The scope of this study is limited to structural framing, exterior and interior walls (an interior wall is the wall that separates the inside the house to the bedroom, kitchen and bathroom etc.). However, floods normally have no effect on roof covering or roof framing. As Table 1 shows, there was no report of damage to the roof structure in flood area, and that might be related to the speed of wind in the case study area. There are many studies that advocate for the reduction of climate change effects related to building construction emissions (Kadir et al., 2015; Balasbaneh et al., 2017a). Other research (Roos, 2003; Sathre et al., 2009) has assessed the effect of different building materials on climate change mitigation. Many studies advise the use of wood as wall material due to its low GHG emissions, and most buildings in flood zones near rivers are built of wood or use wood as the main building material in both their interior and exterior. However, the question remains whether timber is a sustainable material in flood-prone areas or not. A study (Carol, 2012) found that floods only hit foundations and walls and do not affect roofs. Therefore, the focus of this study is on interior and exterior walls; however, the foundation falls outside the scope and it is assumed that all case studies have been built on the same foundation structures. Thus, in order to compute structural performance, cost, and GHG, this study analysed five different building structures in order to optimise alternative building schemes for flood zone areas.

Bradley et al. (2016) assessed the effect of simulated flooding on the structural performance of light-frame timber structures. Load tests were conducted and results showed significant losses in mechanical strength for the wet and restored walls. Yoshihisa Miyata et al. (2015) reported the influence of flooding on steel-strip-reinforced soil walls. Noshadravan et al. (2014) include hazard-related maintenance and building energy usage costs for wood-framed single-family residential buildings exposed to earthquake and hurricane hazards; however, environmental impacts of the materials used for initial construction and repairs were ignored. Another study (Kelman, 2002) performed a vulnerability assessment of the use of unreinforced masonry walls in residential buildings using flood depth. Many previous studies have discussed damage by flooding such as Dutta et al. (2003) or Smith et al. (1998); however, this research only considers the cost for repair of damage and not the magnitude of damage to the environment related to any height of flooding. According to (Merz, 2010), there are two types of flood damage, which are direct and indirect damages. Direct damages occur when flood water directly hits humans or properties, whereas indirect damages are caused by the direct impacts and occur outside the flood event in terms of time and space. Damage can be sub-classified into tangible and intangible. Tangible damages are defined as damages which can be specified in monetary values, while intangible damages cannot be assessed in monetary terms. On the basis of the aforementioned classification of damages, the damages considered in this study fall into the direct, tangible category. Table 1 presents a comprehensive view of the full direct and tangible damage (Merz, 2010) that might occur to residential buildings. The damage has been evaluated on single-storey buildings; however, the amount of damage might be lower for multi-storey buildings (Penning-Rowsell et al., 2005).

The most intense climate phenomena related to natural disasters in Malaysia are flash floods and monsoons, affecting flood-

Table 1
Damage overview of flooding into residential buildings (source: observation of site).

1	2	3	4	5	6	7	8
Fabric	Structure	External Wall	Internal Wall	Permanent Utility	Movable Utility	Human Facility	Food
Building Surroundings Roads Vegetation	Foundation Columns Beams Staircases	Brick Concrete Blocks Steel-Panels Wood Precast Concrete Etc.	Unmovable Interior Walls/Movable Interior Walls	Pipes Wires Water Supply Gas Pipes Water Tanks Sinks Kitchen Cabinets Windows Doors	Furniture Tables Iron Carpets Fans Air-Conditioners TVs Kitchen Equipment Linoleum Pillows Rugs	Personal Computer Clothes Shoes Etc.	Consumable-Food (Dry & Wet Food)

prone areas of about 29,000 km^2 and more than 4.82 million people (22% of the population) while inflicting an annual damage of USD 298.29 million (Aldrich et al., 2014). Flood risk is high, most notably in riverine areas and coastal flatlands. Permanent utilities are perpetual things that remain in buildings even if residents change. Table 1, which can also be used for other disasters such as hurricanes and earthquakes, will be used for future damage assessment of categories of residential building other than walls in flood zones. Therefore, direct damage (Parker, 1987) due to flood disasters was assessed for alternative wall-building materials (Item 3 & Item 4) to mitigate the impact of flooding. Indirect damage consists of cleanup and is assumed to be constant, so it was not included in this assessment. According to research (Sulaiman et al., 2016; Douben, 2006), one-third of Malaysian people believe that flood damage to buildings is the greatest problem arising from flooding in residential areas. The remainder of this research describes existing concepts for damage estimation. Section 2 provides the study background, Section 3 covers the damage resistance percentages of each material, Section 4 presents the LCA analysis, Section 5 presents the LCC assessment, and Section 6 is the last step of the sustainability assessment for the LCC and LCA.

2. Flood damage assessment methodology

The first step is to identify the magnitude and intensity of the flood. Flood disasters can be categorised into flash, mud, monsoon, urban, coastal, tide surge, riverine, etc. (Ang Kean Hua, 2015). Monsoon floods cause destruction and changes in the physical characteristics of local residential buildings (Chan, 2012). The performance-based assessment of buildings after a flood event involves many parameters. The most critical parameters are flood factors (depth) and building properties. In order to compute building performance, flood depth should be identified first. Therefore, local residential buildings owners need to adapt to monsoon floods by choosing the most appropriate local building material which is less impacted by flooding. Fig. 1 shows the general scheme of methodology for this research. In the current research, the velocity has been assumed to be the same for all case studies and the only alternative impact is the flood depth.

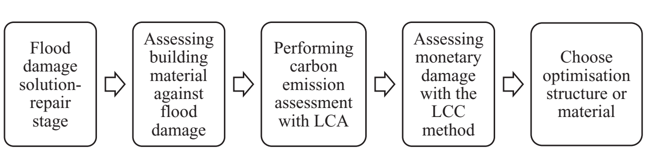

Fig. 1. Scheme of methodology.

2.1. Vulnerability of the structure type to flooding

In this research, the vulnerability of the structural type of a building is defined only by the damage to the wall of a building, without considering other parts of the building, for instance the structural column, roof and ceiling. The vulnerability of the structural type of a building is determined by the percentage of damage to the wall materials resulting from the occurrence of the flood. Vulnerability means the degree of loss of a given element at risk or a set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude (UNDRO, 1991). The difference between calculating GHG emissions and cost incurred from normal buildings and from buildings located in flood zones is related to the quantity of wall materials that needs to be exchanged or replaced after a flood. Furthermore, any building material or structure has their own life span and different resistance to flooding. The objective of this study focuses on repairing buildings post flood damage using different types of building materials for the same structure. Fig. 2 shows what components of a wall have been repaired or replaced after flooding at the renewal stage.

In this study, only new buildings less than 10 years of age have been surveyed under flood conditions. Historical buildings have not been considered in this study owing to their complexity and the likelihood that most traditional buildings are constructed of materials that are rarely used today. Comprehensive research on historical buildings can be found in Che Ani et al. (2009), which focused on the defects in very old buildings. No flood situation was considered, and, for all scenarios, only regular painting was given consideration following previous research by Balasbaneh et al. (2017b) and Iyer-Raniga and (Wong 2012).

Objective data are collected through controlled experimentation or polling. Subjective data include an element of opinion or personal feeling. First, objective data have been collected to identify the elements at risk relevant to a flood vulnerability assessment in residential areas. Initially, this research classified the elements at risk into two major elements: the structural type of the building and building contents. However, given the complexities and findings from the field, it was decided that more detailed classifications of the elements at risk be generated. The objective was to assess the damage to each structural type of building, as shown in Table 2. At the first stage, residents were asked to specify the area of damage and in the next step the estimation of damage was surveyed by the researcher. Therefore, subjectivity had no effect on the result and all observable data are considered to be objective.

The classification of flood risk is based on historical flood data and local weather effects. Flooding depth has a different impact on structures. Most stage–damage functions include water depth as

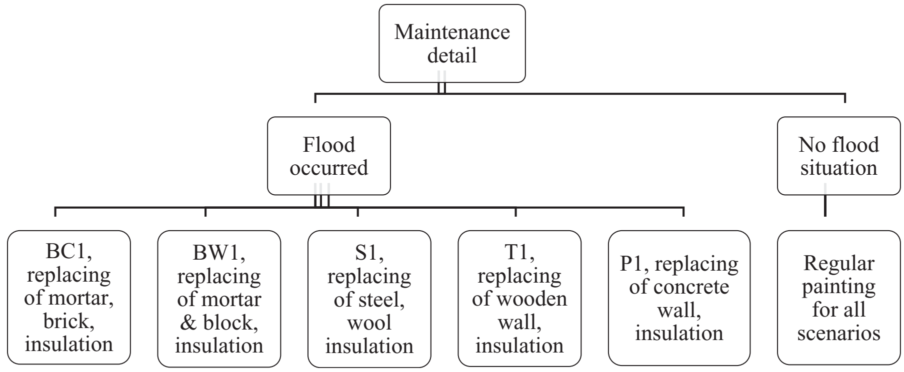

Fig. 2. Diagram of maintenance detail scenarios.

Table 2
Risk analysis according to the Federal Emergency Management Agency (source: FEMA).

Types of Building Materials	*Building Materials Wall*	*Classes of Building Materials*				
		Acceptable	*Adequate*	*Unacceptable*		
		5	*4*	*3*	*2*	*1*
Brick, Common (Clay)	*BC1*		■			
Concrete Block	*BW1*	■				
Wall Panels, Steel	*S1*			■		
Wood, Solid, Standard	*T1*				■	
Precast Concrete Framing	*P1*	■				

the main determinant of direct damage (Lin, 2017). There are other factors that affect flood damage such as flood duration, sediment concentration, flow velocity, and contamination, although, except for depth damage, the factors are scarcely included in flood-loss models. Energy savings from the demolished building materials after flooding are not considered in the life cycle energy estimation of the buildings and it is assumed that all dismantled material is sent to landfill. This is primarily due to the fact that there is no common agreement on attributing this saved energy to the demolished building. Table 3's damage dimension is only applied to the building material, and therefore is not applicable to other categories and items in Table 1, such as furniture, etc. Only the main material of the building has to be replaced when flooding hits the walls, and some other materials such as plasterboard maintained their integrity and mechanical properties and were not considered for replacement in the flood stage (Wendt et al., 2004), having dried to pre-flood levels during the drying period.

2.1.1. *Detailed assessment of the flood vulnerability of the case study in flood zone*

The physical vulnerability to flooding for each structural type of building has been assessed based on flood-depth and damages. The data collection at the site also followed Sagala (2006), which used interviews about site observation. To describe the extent of flooding, interviews were conducted with residents of 85 households along with a local authority staff expert. The extent is separated into two stages of flooding: low and high flood. The depth of a low flood is assumed to be about 50 cm and the depth of a high flood was assumed to be about 150 cm. In general, the interview revealed that the flood lasted for 48 h (Table 2). The vulnerability of the structural type of building is determined from the percentages of damage to the wall material resulting from occurrence of the flood, which follows previous research by Sagala (2006). To get the best result from respondents, a method was used to determine the percentage of damage to wall material. Five levels were used

Table 3
Definition of vulnerability of structure type.

Types	Level	Description
1	X1	If the material needs minor repair, up to 5%, such as only painting
2	X2	If area hit by flood water needs repair and replacement, up to 10%
3	X3	If area hit by flood water needs repair and replacement, up to 15%
4	X4	If area hit by flood water needs repair and replacement, up to 20%
5	X5	If area hit by flood water needs repair and replacement, up to 30%

(Table 3) to estimate the level of vulnerability. This method follows Kelman and Spencer's (2002) research. During the interview the following working definition was used and the respondents were asked to define the damage on the basis of the condition of walls.

A vulnerability level of X5 means extreme damage occurs only to the wall area hit by flooding and the house owner needs to replace 30% of the whole wall, but it does not mean that the house will collapse, as other parts such as ceiling, column and roof remain stable. This occurred to the wooden structural type, which is prone to water but can still continue to cope with flood water. The damage estimation is similar for other levels. For example, X4 means 20 percent of material affected by flooding needs to be replaced in either low flood or high-flood situations. X3 means 15 percent of a wall hit by flooding needs attention by the owner in both low-flood and high-flood situations. X2 also means that 10 percent of a wall surface and material needs refurbishment after flooding recedes and, finally, X1 represents a situation where flooding does not have a profound effect on any material except the surface, which can be fixed by applying paint and material, hence no need for replacement in this situation. Although a structural type such as concrete is strong against floodwater, in some cases minor damage, which is still less than 5%, can still be repaired. That remains the best method in the absence of required damage data in the locale.

Table 4 shows the magnitude and relationship between different materials against flooding effects and the technical performance and relationship extracted from the resistance of each material. It should be noted that the flood depths used to construct the relationship between flood depth and damage are measured by depth inside the house. It is notable that the most damage that was observed and recorded was not more than 30% of wall surface in both low- and high-flood situations and that might be because the flood receded from the land after 48 h.

However, interior details of exterior walls differ from wall to wall. For example, for precast concrete we have concrete, polystyrene insulation and gyprock plasterboard, while, for steel, there are staggered steel studs, wool insulation and plasterboard. Details can be found in Table 5. Fig. 2 shows what needs to be replaced in the maintenance phase after each flood and Table 3 shows the percentage of each material that needs to be replaced by new material.

At this stage, the aim of using FEMA is to justify the results that were compiled (Table 3) in the current research. In fact, FEMA (Table 4) has been used as reference for validation of data. Hence, material that is considered acceptable by FEMA has only about 5% damage (X1), while material such as wood with 20% of damage (X4) is considered unacceptable in a low-flood scenario. The situation for a high-flood scenario followed the previous stage and confirms the damage on the basis of FEMA, which means adequate leads to less damage and unacceptable leads to a higher percentage of damage. Thus, the local data from the field comply with general FEMA data. Sagala's (2006) damage measurement was accomplished in the Philippines, which has the same tropical situation and atmospheric weather conditions and is located in the same flood zone. The experimental modules were tested only for resistance to physical degradation that results from the wetting and drying cycle associated with flooding. The data are also confirmed by this study and indicated that wood material is most vulnerable and concrete or block is damaged the least.

Table 4
Vulnerability function for each structure type of the houses (source: data collection).

Types of Building Materials	Building MaterialsWall	Depth of Flooding	
		50 CM	150 CM
Brick Common (Clay)	BC1	X2	X3
Concrete Block	BW1	X1	X2
Steel Wall Panels	S1	X3	X4
Wood, Solid Standard	T1	X4	X5
Precast Concrete Framing	P1	X1	X2

Concrete and brick walls consider replacing interior finishes partially as much as wall surface affected by flood (Table 3). For example, in low flood, only 5% of wall surface were damaged when using concrete block (BW1) and 10% of wall surface in the case of high flood depth. Therefore, that area was replaced with new material.

However, two stages of flood, minor repair (low depth) and major repair (high depth), were considered in order to determine the effect of both situations on wall materials. Owing to the rainy seasons, Malaysia is prone to floods from rivers. Malaysia has 189 water basins and an average rainfall of 2,000–4,000 mm per year, making both low and high floods a significant risk. When floods around 150 cm in depth occur, the usual result is critical damage to the building's wall, and normally more depth than that will lead to having to fully demolish the walls and even roofs (especially on timber structures). The scope of this research is to assess the refurbishment and repair of walls if the structure is still available. Another advantage of assessing two levels of flood depth is to determine the extent of each type of damage to the building and to show whether steady damage affects the walls or if the damage escalates as foreseen. Some areas in Malaysia, such as Kelantan, only face high flood depth owing to their location near the river and basins. Some other areas, however, owing to their distance from rivers and basins, are normally only hit by low flood depth. The limitation is that bacteriological testing and toxic materials testing were not performed during this series of tests.

2.2. Methodology for sustainable assessment

2.2.1. Life cycle assessment – global warming potential (GWP)

LCA is a tool for quantifying the environmental performance of products that takes into account the complete life cycle, starting from the production of raw materials to final disposal. LCA has been applied to different stages of building maintenance under flooding in Malaysia. The boundary for assessing life cycle research in this study will be cradle-to-grave, which is inclusive of the raw material and construction, transportation, maintenance and replacement (related to flood) and, finally, end of life (demolition). The architecture model in this study represents a single-family house in Kuantan, a Malaysian city located in a flood zone. The model was assessed using SimaPro 8 software for environment carbon emissions. The study is limited to refurbishment of the damaged materials which needs to be replaced. The materials were considered as landfill since it was not clear what scenario considered in the end of life of the materials.

2.2.2. Life Cycle Inventory

The definition of Life Cycle Inventory (LCI) is based on the calculations of energy use by the product or the processing of raw material to system boundaries as well as the total inputs and outputs of the system (Ekvall, 2004). The database procedure was acquired from the Ecoinvent database. The Ecoinvent database was adopted to the case study using local electricity mix data sets from previous research on Malaysian conditions (Balasbaneh et al., 2018a). However, in order to produce significant results and total proper outcomes, a Malaysia Life Cycle Inventory Database (MYLCID-2016) was applied in the LCI to adjust for raw materials such as cement and diesel. Electricity was used for the assessment of raw materials used in saw mills for timber production or prefabricated concrete and is considered a fossil fuel, accounting for 96.63% of electricity production in Malaysia in 2014. The reason for this

Table 5
Characterisation of scheme components buildings.

Buildings scheme	Residence building scheme	Wall components	Thickness (m)	Transportation of material to the building site	Total weight (kg)
Block-Work System	BW1	Block	0.4 × 0.3 × 0.2	Lorry > 32 ton, 30 km	24,440
		Mortar	0.4	Lorry 16 ton, 7 km	1,674
		Polystyrene insulation	0.03	Lorry 16 ton, 40 km	180
		Plasterboard	0.03	Lorry 16 ton, 20 km	2,715
Precast Concrete Framing	P1	Concrete	0.200	Lorry 16 ton, 10 km	60,370
		Polystyrene insulation	0.03	Lorry 16 ton, 40 km	180
		Gyprock Plasterboard	0.03	Lorry 16 ton, 35 km	176
Steel Frame Work System	S1	Staggered Steel Stud	0.2	Lorry 16 ton, 40 km	5,462
		Wool Insulation	0.15	Lorry 16 ton, 60 km	3,225
		Screw	-	Passenger car 4 km	18.7
		Gyprock Plasterboard	0.0125	Lorry 16 ton, 35 km	2,930
Timber Prefabricated	T1	Wood	3 × 0.15 × 0.12	Lorry 40 ton, 10 km	29,276
		Screw	-	Passenger car 4 km	58
		Polystyrene insulation	0.03	Lorry 16 ton, 40 km	180
		Plasterboard	0.03	Lorry 16 ton, 40 km	180
Brick - Common (Clay)	BC1	Brick	0.15	Lorry 16 ton, 30 km	46500
		Mortar	-	Lorry 16 ton, 25 km	1674
		Polystyrene insulation	0.03	Lorry 16 ton, 40 km	180
		Plasterboard	0.03	Lorry 16 ton, 20 km	2715

adoption is because electricity production in Malaysia is 95% fossil fuels.

Any LCA study should define a specific functional unit to describe proper inputs and outputs based on ISO-14040, 2006 (Principles and Framework, 2006) to validate the study by comparing two or more fundamental processes or products. This functional unit is used as a reference in product comparison. The functional unit of this study is building living areas over a period of 50 years, as in previous research (Balasbaneh et al., 2017b). LCA attributional modelling was applied to investigate building schemes.

The maintenance for non-flood situation, i.e. when there is no flood (first scenario), was assumed to involve regular maintenance such as painting of wall surface. If there is flooding, whether low or high, the maintenance follows the steps shown in Table 3. The regular maintenance activities include painting of walls and varnishing of wood surfaces every 10 years based on the report by National Association of Home Builders (NAHB), as suggested by (Iyer-Raniga and Wong, 2012), or four times over a 50-year life time (Shafie, 2007). It is assumed that flood recurrence hits the building once during the 50-year life span of the building. Approximately 33% of the population agrees that water damage to building is the main effect of flooding (Durumin Iya et al., 2014).

2.2.3. Life cycle impact assessment

Life Cycle Impact Assessment (LCIA) describes global warming potential (IPCC GWP) using 100-year time spans. The reason for this method is that CO_2 emissions into the atmosphere have a long-term effect and will not easily disappear. The IPCC GWP 100 has a defined mid-point indicator, which normally stands for environmental situations that require solutions to current problems based on international conventions such as GWP. Climate change (IPCC, 2014) represents the emission of greenhouse gases. IPCC defines it as the impact of carbon dioxide (kgeq-CO2 eq into air/kg emi) on climate change. LCIA converts ‘inventoried’ flows into simpler indicators. A prominent method for assessing the effect of global warming is the life cycle impact assessment of IPCC GWP (The Intergovernmental Panel on Climate Change). A definition adopted by the IPCC defines flood risk as hazard x, exposure x, and vulnerability (Kron, 2002).

2.2.4. Life cycle cost

If the cost of improvements or the cost to repair damage exceeds 50% of the market value of a building, it must be brought up to current floodplain management standards. This is called a substantial improvement (FEMA, 2008). Data on input costs, such as building material, transportation, and disposal, are the same as data used as inputs in SimaPro 8.3 to evaluate environmental impacts. In addition, LCC along with LCA is part of eco-efficiency product approaches.

The LCC approach is the estimation of all related costs throughout the life span of a building and costs at their Present Value (PV). In this study, the LCC assessment follows the approach introduced by Islam et al. (2014), Islam et al. (2015a, b). Future costs were estimated within the boundary of this calculation, and its related items are demolition and building maintenance. Maintenance costs include items such as repainting, replacement, and repair associated with flood damage over a 50-year time frame. The PV of a future cost is the same as in previous studies (Langstone, 2013) and is estimated based on the calculation of suitable discount rates and future inflation. In this study, the inflation rate was considered the average Malaysian inflation rate over the last 5 years of 2.44% (inflation rate, 2016). The base year for analysis was 2015, the year the study was undertaken. The future cost and discounted present value were calculated using equations (1) and (2), respectively.

$$\mathrm{FC} = \mathrm{PV} \times (1 + \mathrm{f})^{\mathrm{n}} \quad (1)$$

$$\mathrm{DPV} = \mathrm{FC} \div (1 + \mathrm{d})^{\mathrm{n}} \quad (2)$$

where FC = future cost, PV = present value, f = inflation rate, n = number of years, DPV is the discounted present value and d is the discount rate.

The resale value was also not included in this analysis owing to a lack of valid and reliable data. Data inputs for LCC for the construction, maintenance, and disposal phases were sourced from a standard construction cost guide handbook (JUBM and Langdon Seah Construction Cost Handbook Malaysia, 2016) and National Construction Cost Centre-N3C (CIDB Malaysia Official Portal, in Malaysian Ringgit (RM). The construction costs included material and labour costs and the design life was taken to be 50 years.

2.3. Building description in the city of kuantan (case study)

The state of Pahang is located in the eastern part of Peninsular

Malaysia. In terms of area and population, it is the third and ninth largest state, respectively. Kuantan is the capital city of Pahang and is located close to the mouth of Kuantan River facing the South China Sea. The heavy rain and flood that occurred in Pahang in December 2014 was the worst in Malaysia since 1971. It caused damages to property, agricultural produce and infrastructure and losses amounted to an estimated RM 610 million (source: http://english.astroawani.com/flood-news/pahang-incurs-losses-rm610-million-23417). This study assesses vulnerability of different building materials against flood to a residential house located in the city of Kuantan. The aerial imagery of the study area is illustrated in Fig. 3.

Architectural elements of the single-family residential building are shown in Fig. 4. These sketches show the walls and other structure details. The house contains three bedrooms, a kitchen, and one living room. Five common building materials were chosen from real scenarios that were the most applicable to residential buildings throughout Malaysia.

Generally, buildings are supposed to be used for 35–100 years before demolition, and, in this paper, an average of 50 years was assumed for the operational stage, with the living area of the house being 115 m^2. In the last stage of the building's life span, it is demolished and its materials are sent to a landfill or burned for fuel. Non-recyclable materials are assumed to be being sent to the landfill.

2.3.1. Data quality and assumptions

The characterisation of each building structure and material quantity is represented in Fig. 5. Regarding data representativeness and data quality, availability is the most fundamental issue for the LCA process. Quantity and transportation rate are necessary categories for assessment and for comparing different structures. Five different building structures are analysed for their performance under monsoon flood conditions. In all case studies wall material used an insulation layer. However, following the research of Balasbaneh et al. (2018a), identical cooling requirements have been assumed for the various scenarios assessed, and, therefore, cooling environmental impacts do not influence the comparison of alternative walls (these are assumed to be independent of the frame material). Fig. 4 shows the detail of exterior wall house scenarios and describes the specific detail of each case study (Item 3 in Table 1). The scheme of an interior wall is the same with the exclusion of the plasterboard. Transportation of materials to building site has been assumed to be a lorry. Malaysian average characteristics and the related inventory data with those processes have been obtained from Refs (Spielmann et al., 2007). and the Malaysia LCI Database (2013).

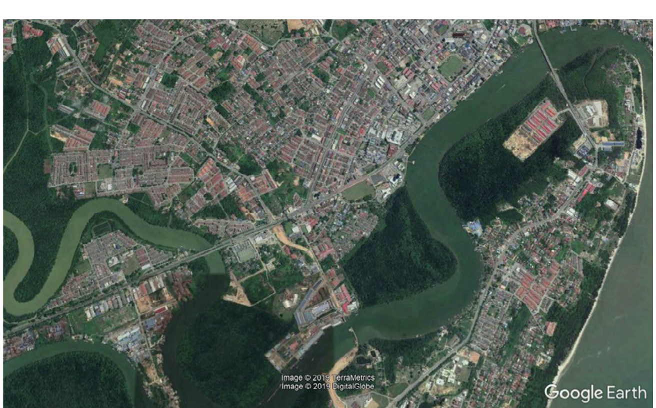

Fig. 3. Aerial imagery of the study area.

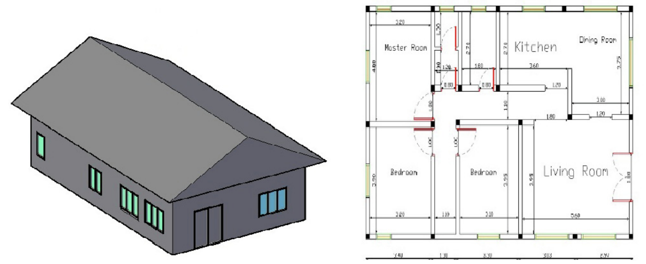

Fig. 4. Architectural scheme of a single-storey residential building.

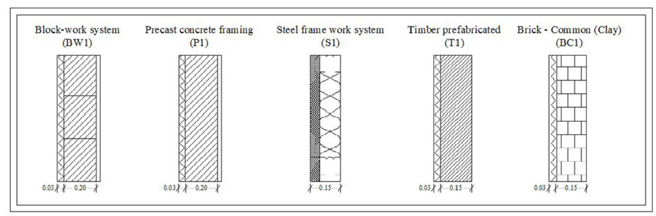

Fig. 5. Exterior wall house scenarios with section details.

There were five different building schemes assessed in this study. The first building material is a block-work system (BW1) with dimensions of 400x300x200 cm. The input related to BW1 for transportation is shown in Table 5. The walls material consists of interlocking block and mortar, while external building envelope insulation consists of polystyrene insulation sheets. For the use phase of building, regular painting maintenance is considered to be done every 10 years and, finally, the end of life scenario is the transfer of retired products to a landfill. Precast concrete framing (P1) is the second scheme, and all components of this frame were manufactured with a density of 2,700 kg/m^3 and gyprock plasterboard has been used to cover the external wall. For end of life, 54 litres of diesel were used for materials transport in the demolition phase and retired concrete is generally disposed of in a landfill.

Steel frame work system (S1) density is 7,850 kg/m^3, for steel studs. The steel structure is comprised of preliminary material, such as steel studs every 50 cm, mineral wool for thermal resistance and soundproofing, plasterboard for its surface, and a screw to attach each panel or part. Cranes and air compressors are needed in the set-up wall process. The steel studs have 0.02 m of thickness, 0.15 m of width, and a weight of 12.5 kg/m^2. In the demolition phase, 70 litres of diesel were used for material transportation to the recycling factory for steel. Plasterboard and mineral wool were sent to a landfill.

Timber (T1) is another material common in river zones which has a very high flood risk. The density of wood is 800 kg/m^3 and the size of columns and beams is 3*0.15*0.12 m. A lorry has been used to transport the timber 10 km to site. Wood has a higher end-of-life primary energy benefit to the environment than steel, concert and interlocking block. In the demolition phase, 40% of wood is re-used and 60% is incinerated as fuel to produce electricity. The last building material is common brick (BC1) with a density of 2,100 kg/m3. The material was sent to a landfill after demolition.

3. Result

When a flood hits residential buildings, partial or substantial repair is needed for wall and surface materials. The early stage of the building's design is the most appropriate time to make decisions about wall materials to improve flood damage protection. In

order to accomplish this, such as aspects as climate change material emissions, costs and resistance life span must be considered.

3.1. Climate change effect from refurbishment and repair of material

The results indicate that proper design and building selection play vital roles in reducing CO_{2eq} emissions in construction. Table 6 shows the result of IPCC GWP scenario analysis for five different case studies. Most research regarding flood damage only assesses direct economic losses and not environmental losses. The results were distributed into normal situations, low floods of 50 cm, and high floods above 150 cm. The assessment supports global warming mitigation using CO_{2eq} emission. When choosing case studies, this study tried to include all building material currently used for real buildings.

The first column in Table 6 is the assessment for when no floods occur. The emissions related to BW1 for normal no flood situations are 19,870 kg CO_2eq, 1,902 kg CO_2eq, 1,531 kg CO_2eq, and 2,540 kg CO_2eq for construction, transportation, maintenance and end-of-life scenarios using the IPCC GWP 100a method, respectively. The emissions from S1 are 16,120 kg CO_2eq, 542 kg CO_2eq, 1,580 kg CO_2eq, and 780 Kg CO_2eq for construction, transportation, maintenance and end-of-life scenarios using IPCC GWP 100a method, respectively. BC1 is a common building material and emissions related to this structure are 13,130 kg CO_2eq, 995 kg CO_2eq, 1,210 kg CO_2eq and 2,100 kg CO_2eq for construction, transportation, maintenance and end-of-life using the IPCC GWP 100a method, respectively.

The second-least environmentally friendly building structure is P1, for which all components were prefabricated in a factory. Emissions relating to this structure are 10,700 kg CO_2eq, 1,210 kg CO_2eq, 1,380 kg CO_2eq, and 2,120 kg CO_2eq for construction, transportation, maintenance and end-of-life using the IPCC GWP 100a method, respectively. Emissions from T1 are 8,064 kg CO_2eq, 1,520 kg CO_2eq, 1,110 kg CO_2eq, and 540 kg CO_2eq for construction, transportation, maintenance, and end-of-life using the IPCC GWP 100a method, respectively. T1 at this stage is the most environmentally friendly building scheme, as proved in previous research (Balasbaneh et al., 2018b).

Fig. 6 shows that floods drastically increase total emissions from walls. This increase is from the maintenance phase. For each building material this emission varied, while both construction and disposal stayed the same. The first survey is related to low-flood assessment, in which the flood depth was low but still damaged walls long enough to reach its materials. The emissions relating to maintenance for BW1 were 1,128 kg CO_2eq for painting and replacing material and 120 kg CO_{2eq} for transportation, which is higher than in non-flood conditions. It is obvious that emissions in the construction and end-of-life scenarios remained the same as normal conditions and only the maintenance phase saw an increase. The maintenance phase relating to S1 is higher than BW1 because the components of this structure, such as wool insulation, were more vulnerable to flood water. Emissions relating to S1 are 2,533 kg CO2eq and 320 kg CO_2eq for maintenance and the

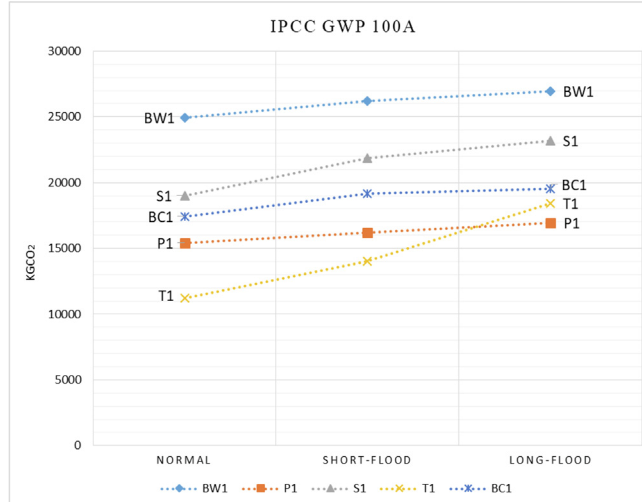

Fig. 6. LCIA IPCC GWP scenario analysis results, block-work system (BW1), precast concrete framing (P1), steel frame work system (S1), timber prefabricated (T1), brick–common (BC1).

transportation of new material to the construction site, respectively, which is higher than non-flood conditions.

BC1 is the third highest emission material, with increased emissions from the maintenance phase being from flooding as a result of material replacement. The emission related to it are 1,533 kg CO_2eq and 210 kg CO_2eq for the maintenance phase and transportation of material to the site, respectively, which is higher than in non-flood conditions. The variation in emissions for BC1 is lower than S1. Emissions slowly increase for P1 due to the high strength of the concrete structure against low-flood damage and increased emissions are mostly related to painting and minor repairs. Emissions were 661 kg CO_{2eq} and 110 kg CO_{2eq} for maintenance and transportation, respectively, which is higher than in non-flood conditions. The last structure T1, which is shown in Table 1, is the material most vulnerable to flood water. Emissions relating to T1 are 2,620 kg CO_{2eq} and 189 kg CO_{2eq} for the replacement materials and transportation, respectively, which is higher than in non-flood conditions. Although results indicate that T1 could be the best option for climate change mitigation, Fig. 5 shows that even under low-flood conditions the maintenance phase has a huge impact on the environment; however, these emissions are still lower than in other case studies.

The third and last category for assessing buildings is high floods. Different buildings have different reactions to high flood depth. The assumption of this study is that damaged material is sent to landfills in all scenarios. BW1 under high flood depths slightly increases its emission compared to normal situations with a 749 kg CO_{2eq} and 1,997 kg CO_{2eq} difference for low-flood and non-flood stages, respectively. From this, 1,997 kg CO_{2eq} and 1,782 kg CO_{2eq} is related to the maintenance of damaged surface walls and 215 kg CO_{2eq} is related to transportation, which is higher than in non-flood

Table 6
Result of assessing five different building frame structures; LCIA IPCC GWP scenario analysis results.

Building Structure	Residence Building Scheme	Unit	Non-Flood	Low	High
Block-Work System	BW1	IPCC GWP 100a	24,953/8	26,201/65	26,950/1
Precast Concrete Framing	P1		15,410/44	16,181/422	16,951/5
Steel Frame Work System	S1		19,022/2	21,875/33	23,207/11
Timber Prefabricated	T1		11,234/42	14,043	18,413/35
Brick – Common (Clay)	BC1		17,436/44	19,179/6	19,528/81

conditions and slightly higher than in low-flood conditions. S1 is also vulnerable to high-depth floods with maintenance emissions of 3,850 kg CO_{2eq} and 335 kg CO_{2eq} for maintenance and transportation, respectively, which is higher than the non-flood assessment. Emissions for BC1 structures for both low and high floods remain almost the same. However, emissions for high floods were 1,820 kg CO_{2eq}, 272 kg CO_{2eq} higher than non-flood situations. P1 under high floods also had a slight change in emissions for maintenance and transportation compared to non-flood conditions, which are 1,310 kg CO_{2eq} and 231 kg CO_{2eq}, respectively. The greatest effect of high-depth flooding was seen in T1 with a high-flood emission of 6,745 kg CO_{2eq}, 434 kg CO_{2eq} higher than non-flood conditions. In normal or non-flood stages, T1 has the lowest emissions, but flooding increases maintenance phase emissions to higher rates than for P1. Therefore, in flood zone areas, P1 is the optimum choice to reduce GHG emissions. P1 is the most stable structure against flooding, as its releases less emissions during its life span in the maintenance phase.

3.2. Cost of building and refurbishment stage from flood damage

Being able to estimate “total loss” after an event is important to support emergency management and to decide on priorities for reconstruction (Molinari et al., 2014). Flooding is the costliest natural disaster event worldwide (Rojas et al., 2013). This study estimated the maintenance phase under two flood conditions. This was determined by comparing the cost of the improvements to the current market value of the building before the improvements. If the cost of improvements equals or exceeds 50% of the market value, then the structure is considered substantially improved. Since there is no forecast about when a flood is to occur, the non-flood, low-flood and high-flood categories were being re-used in this section. This study aims to produce high-flood resistant buildings with low costs and low environmental impact for high-flood risk areas in Malaysia.

LCC in non-flood situations was assessed and the next stages were created based on the material replacement required owing to flooding. The highest cost, as shown in Table 7, is P1 due to its construction stage costs of RM 235,059, of which RM 15,849 and RM 13,205 are for maintenance and end-of-life disposal, respectively. Maintenance costs consists of repair and replacement, for low flooding and high flooding, of RM 15,846 and RM 30,373, respectively. S1 had a lower cost than precast, putting it in second position. The costs for S1 in non-flood conditions are RM 20,8336, RM 24,509, and RM 12,255 for construction, maintenance and end of life, respectively. The extra cost for low flooding is RM 41,667 greater than for non-flood conditions, and high flooding is RM 57,598 higher.

BW1 and BC1 are the most suitable structures because they show less variation in all three stages and have the lowest costs compared to S1 and P1. The cost for BW1 was RM 203,578, RM 13,725 and RM 11,437 for construction, maintenance and end of life, respectively, for the non-flood assessment. The maintenance phase for low flood and high flood increases cost by RM 27,449 and RM 34,311, respectively. The BC1 cost for non-flood conditions is RM 199,453, RM 14,567 and RM 10,084 for construction, maintenance and end of life, respectively. Maintenance costs showed an increase of RM 22,410 and RM 26,668 for the low-flood and high-flood stages, respectively. Material damaged during flooding was sent to a landfill. The lowest cost structure for residential housing is a timber structure.

Table 7
Life cycle cost of alternative wall assemblies.

Building Structure	Building	Unit	Non-Flood	Low	High
Block-Work System	BW1	RM	228,740	242,464	249,326
Precast Concrete Framing	P1		264,112	279,958	294,485
Steel Frame Work System	S1		245,101	286,768	302,699
Timber Prefabricated	T1		205,010	250,113	323,915
Brick – Common (Clay)	BC1		224,105	246,515	250,773

T1 presents the most efficient costs if there are no floods. Its costs are RM 153,757, RM 41,003 and RM 10,250 for construction, maintenance and end of life, respectively, for the non-flood assessment. However, LCC showed a significant increase with low flooding and maintenance costs rising to RM 45,104. Under high flooding, maintenance costs rose to RM 118,905. As seen in Fig. 7, three variables are changed, as seen in the low-flood stage. First, when floods hit the wall for S1, the maintenance of S1 rose. However, the effect of S1 still increased more than P1 and this increase continued throughout the high-flood stage. When floods occur, S1 has lower retrofitting costs.

T1 has fewer costs during construction and building life span if there are no huge maintenance and refurbishment costs due to flooding. In fact, in non-flood zones this structure could be an ideal option. Flooding has a huge impact on T1, and in the low-flood stage its costs exceed BW1 and BC1. For high flooding, its costs can be higher than S1 and P1. The result shows that although T1 shows low GHG emissions, it is the most expensive option. The most ideal building structures in terms of cost are BW1 and BC1. In the normal life span of a building, BW1 has a slightly higher cost than BC1. However, for the low-flood stage, the results show a higher BC1 cost, and, in the high-flood stage, both BW1 and BC1 have the same cost. In conclusion, both structures have ideal costs for construction. A comparison of T1 and S1 between rehabilitation versus demolition shows the following: T1 favors demolition because of the high cost of the rehabilitation process after high flooding, as wood is the worst option for construction. Rehabilitation was also not considered the most economical solution for S1.

3.3. Sustainability assessment

To assess the sustainability of building material maintenance under the non-flood and variable flood stages, a benchmark system was developed. This benchmark system combined the two

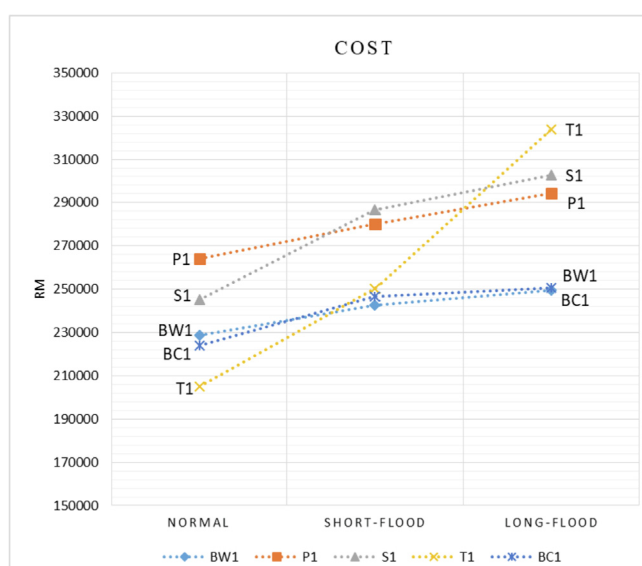

Fig. 7. Life cycle cost, block-work system (BW1), precast concrete framing (P1), steel frame work system (S1), timber prefabricated (T1), brick–common (BC1).

proposed assessment categories, environment and cost, as observed in Fig. 7. This approach is commonly used to show the combining of two linear independence parameters such as that performed by Escamilla (2016). The materials were compared using global warming emissions and costs based on flood resistance in tropical areas. To compare different materials and structures, their CO_2eq emissions and cost were combined into one system. The objective of this study was to determine whether or not wood should be used in high-flood risk areas. Sustainability was assessed using a benchmark system that incorporated the result of these two categories.

The results for global warming are shown on the x-axis, and results related to cost are shown on the y-axis. In this benchmark chart, the best performance is located near the origin where cost and global warming emissions are lowest. It is obvious that all building schemes have higher emissions and costs in the second and third stages of flooding because damaged material needs to be repaired and replaced. In this scenario, the full LCA shows that T1 in non-flood conditions is the ideal structure due to its low CO_{2eq} emissions and cost. This result is supported by previous research.

In Fig. 8, S1 and T1 are the structures that showed the most variation during assessment. In the normal life span of a building T1 is considered the best option for residential buildings owing to its low cost and GHG emissions. In the third stage (high flooding) T1 is the worst option on the basis of FEMA because its cost to repair damage exceeds 50% of building construction value, meaning, on the basis of FEMA, it is better to construct a new building. Therefore, this study advises the elimination of timber housing construction in areas with high-flood damage. The second structure with the most variation is S1. Even in normal conditions S1 is not considered the best construction option, and after flooding it shows higher maintenance costs compared to other structures such as BC1 or BW1. Therefore, it is not advised for use in flood zones, as its refurbishment and repair cost is one quarter of its construction cost.

The arrow in Fig. 8 shows the variance of T1 and S1 from non-flood conditions to high-flood conditions and its correlation with LCC and GHG emission. Although the researcher believed that wood was friendliest material, the results indicate that flood effects on the maintenance phase make it an unreliable material for construction. The meaning of sustainability in the context of this study is material that is most sustainable in terms of cost and emission in a flood zone. This study investigated the sustainability of materials in three conditions of non-flood, low-flood and high-flood conditions. In non-flood conditions sustainability means assessing the embodied energy of material by calculating CO_2 and cost during its life span, while in flood condition the embodied energy has been assessed by considering the resilience of material against flooding during the occupation phase of the building. Many researchers have pointed out that timber is a more sustainable and friendlier material because of its ability to capture CO_2, while the result of this study states that timber is not sustainable anymore in flood zones, mainly because of its high vulnerability against flood water and its high cost of refurbishment and replacement.

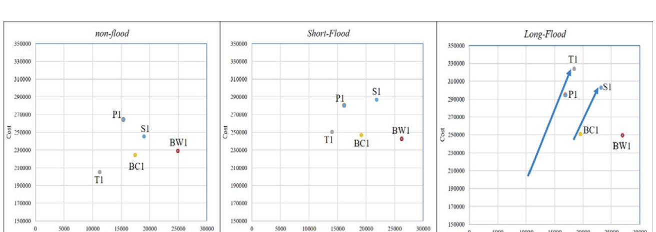

Fig. 8. Block-work system (BW1), Precast concrete framing (P1), Steel frame work system (S1), Timber prefabricated (T1), Brick (BC1).

The scope of this study focused on building maintenance phases after a flood. The refurbishment costs of BC1 compared to T1 and GHG are 29% and −5%, respectively, for high flooding. In comparison, P1 and T1 cost and GHG are 9% and 8% higher for high flooding. The finding of the current research shows timber as the best material for construction, but this study shows that in flood zones, timber is a poor option, as P1 is cheaper and GHG is more environmentally friendly. The results of this study can be applied to other regions that have been suffering flooding in the last few decades. This study may change energy policy for assembling and choosing building materials in flood zones all around Malaysia and other countries in South East Asia. Thus there is a real need to change the way buildings in these areas are designed and how damage can be mitigated and managed. On the basis of FEMA, some materials such as precast concrete or blocks are the most appropriate material during flooding but this research found that either their cost or GHG emission in the maintenance phase was higher than for common brick. The result of this research can be applied to other regions with the same capacity for flooding as long as the flood water has not been contaminated with factory pollution and is not toxic.

Although FEMA (Table 4) represents block and precast as acceptable material in a flood zone, the result in this study shows that after maintenance, their GHG and cost make them the second or third choice for building. In contrast, brick is known as only adequate material because assessment has shown that its refurbishment and repair has lower emissions. Therefore, at the beginning it might look that replacement of 5% concrete or block compared to 10% brick makes it a better option for building construction because the quantity of brick is higher or the repairers need more raw material in the maintenance phase. In reality, 10% of brick costs less economically and environmentally and requires less effort than concrete in high-flood situations. Consequently, this study advises the use of the most optimum material from benchmark study to be built in high-flood zone areas. To help further expand the field of knowledge, future research can assess different types of building foundations. It also can assess the social effect of flood disasters on building occupants and their losses and also how they affect the occupant's life. In that instance, Table 1 can be used as a map for estimating the damage to human life. For future research, the study suggests assessing the effect of wind pressure damage on different building structures and estimating the cost of each building material.

Although there are versatile types of wood available in the market, the wood that has been assessed as building material was hardwood, the one mostly used for construction purposes in Malaysia as well as in many other countries.

With the comparing of four different prefabricated and traditional structures in flood zone areas and after collecting the damage assessment data, the result can be applied to all areas near rivers or coastal areas in which the flood velocity is not heavy enough to move the structure or totally destroy the wall panels. In addition, the result of this study can be used for both local and global construction to produce sustainable solutions for minimal post flood disasters as long as the new construction technology such as steel, timber and concrete have been used. Therefore, brick is the best environmental solution in this scenario, and timber, nominated as the best environmental solution, has performed the worst as a material and structure in terms of both environmental and cost issues.

Most of the rivers in Malaysia originate in tropical jungle, where there is no factory sewage and contamination mixed in with water, and most flood zones are located near these rivers. Additionally, there is no report on structural damage on any building. The effects of different contaminations on building materials can be assessed in future research.

4. Conclusions

Historically, catastrophic flood events in Malaysia reveal that flood disasters have not been adequately prepared for in this country. Increased population and urban growth have led to the conversion of open spaces, which can cause flooding. Since preventing floods seems impossible, the building sector should apply new rules to reduce damage for buildings located in the flood zone. This study determines the contribution of each material after flooding to greenhouse gas emissions, maintenance and refurbishment costs. This study helps choose appropriate materials for buildings located in flood zone areas. The objective of this study was to identify what material type was more suitable as wall material in the flood conditions in Malaysia.

First, life cycle assessment SimaPro software was employed to assess the greenhouse gas emission and life cycle cost was used to provide the full cost of the project plus the quantity of damage related to each building material. Materials were assessed based on their repair cost and greenhouse gas emissions in two situations (low flood and high flood). The assessment of greenhouse gas emissions identified wood as an ideal building material in non-flood conditions. After flooding, the maintenance phase increases maintenance costs due to the replacement and transportation of new material. However, replacing requires the use of new material which increases the greenhouse gas emissions by the building sector. Hence, prefabricated timber has been shown as the worst amongst alternatives. Precast concrete framing is an ideal choice in flood zones owing to its low emissions but not its cost. The block-work system also shows to be the less variable in terms of both cost and greenhouse gas emissions among the alternatives, which means less damage during floods. However, since the block-work system has a high initial cost and emission, it cannot be recommended for construction. Common brick showed the most stable costs and emissions after flooding in the refurbishment stage. Finally, although the steel frame work system shows predictable variables under flood, it still shows the highest rates in both cost and greenhouse gas emissions categories compared to other alternatives.

The benchmark used three stages, non-flood conditions, low-flood conditions, and high-flood conditions. To finalise decision-making based on both life cycle cost and life cycle assessment, brick is the most ideal materials, and steel wall panels and timbers are the least ideal materials in flood zones. However, the greenhouse gas emissions of steel wall panels are slightly higher than of timber but costs significantly less. While most buildings in flood zones around rivers are constructed of wood, there should be a policy to construct new buildings using bricks. First of all, those buildings in high-risk flood areas must be different than those in inland construction (where the risk of flooding is minimal). This study recommends the use of timber for non-flood prone areas and brick for flood prone areas as building materials. The alternative design in flood zone regions is brick structure, as it shows fewer variable changes on both cost and environment emission issues. Other materials that have recently been assessed either have a higher cost or greater emissions in their refurbishment stage after flooding. The findings of this study can be used to propose that governments assist in developing further policies for high-flood risk areas, ensuring sustainable buildings are constructed to mitigate climate change.

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